

Ideal Black Hole Gas

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The concept of primordial black hole creation in the early universe has been a common theme in early cosmological scenarios.<sup>1</sup> In this letter we put forward the concept of a primordial black hole fluid with intrinsic spin density and its consequence for supercluster-sized, i.e. large-scale voids, and the missing mass question.<sup>2</sup>

It has been hypothesized that the mass of primordial black holes<sup>3</sup> range as far down as the Planckian mass limit of about  $10^{-5}$  gm. On the other extreme, primordial black holes with a mass of about  $10^{15}$  gm should now be in the final stages of Hawking evaporation.<sup>4</sup> At one time, it was thought that these latter black holes were candidates for gamma-ray and x-ray bursts. However it appears more likely that these events are associated with the dynamics of solar remnants.<sup>5</sup> Thus it would be likely, within the original scenario, that either these relic black holes were not created with sufficient mass to survive until the present epoch or that they were just simply not created at all. There is, however, the supposition that the lifetime of the inflationary era is associated with the evaporation time for the primordial mini black holes. This would mean that the primordial black holes would have been created with masses consistent with the evaporation time scale.<sup>6</sup> What follows does not in principle conflict with this hypothesis although it probably modifies the time scale somewhat and makes our scenario more difficult. On the other hand, quantum mechanical arguments have been put forth that suggest that the ultimate remnants of an evaporating black hole is a degenerate gas of Planck mass black holes called planckons which are stable against further decay due to the onset of quantum stability of the "lowest" state of a black hole.<sup>7</sup> If this is the

case, our scenario would be easier to construct. However, the consistency between the temperature of the evaporating mini black holes and that of the planckons seems to contradict the principle of Hawking evaporation and the existence of the planckons themselves. That is, the planckons must be relatively cool, or they would interfere with the big bang relic 3 K black body radiation. We do not know how this can be overcome, but the thermodynamic description must somehow be replaced with a quantum mechanical decay process especially in the latter stages of evaporation. In either case, what we present is far from the planckian limit and thus well within the classical realm.

Recent observations supports the existence of significant large scale structures<sup>8</sup> with extent greater than 80 Mpc. It is in fact likely that some of these objects may not even be visible, such as the recently discovered object in the constellation Leo which, it is conjectured, supposedly lenses a quasar over 1.6 Gpc distant.<sup>9</sup> The existence of large scale voids with diameters of the order of 100 Mpc seem to be a consistent with this structure.<sup>10</sup> The general features of the universe shows a vast network of clusters, filaments, and voids as is evident in the analysis of the Shane-Wirtanen survey.<sup>11</sup> Combined with these general features is the question of the missing mass which is usually attributed to massive neutrinos,<sup>12</sup> axions,<sup>13</sup> strings,<sup>14</sup> Higgs boson decay,<sup>15</sup> or other generally unspecified cool or even hot dark mass.<sup>16</sup> The existence of large quantities of dark matter seems to be indicted for instance by infall in the Virgo cluster;<sup>17</sup> however this dark matter is probably not composed of baryons.<sup>18</sup> In this note we propose that this missing mass be attributed to an ideal black hole gas with

sufficient intrinsic spin density to avoid collapse and collocated with the large scale voids.

In order to avoid confrontation with the 3 K black body background radiation field, which appears from experimental measurements to be highly isotropic with quadrupole or higher multipole moments consistent with zero,<sup>19</sup> we assume that the temperature of objects within the "voids" have an average temperature close to the background blackbody temperature. This imposes two constraints on a black hole fluid which must be met: the fluid temperature itself must be in equilibrium with the background radiation field, and the surface temperature of the mini black holes must also be near 3 K.<sup>20</sup>

We assume that during the early stages of the big bang, mini black holes, with possibly some intrinsic spin will be formed. Thereafter the black holes can grow by accretion of other black holes. During the accretion process, the spin of the black holes will tend to increase both through the union of individual spins and the absorption of the relative orbital angular momentum of colliding black holes (and perhaps ordinary matter). This tendency for the intrinsic spin of the daughter black holes in black hole coalescence to increase is due to the randomness of both the initial spin distributions and the collisions between pairs of blackholes. This means that the random walk absorption of the intrinsic spin of the newly formed black holes after each union will favor an increase in spin angular momentum of succeeding daughters.

Consider a large scale, supercluster-sized void with diameter 100 Mpc. If we assume that the initial matter density in the void is the same as elsewhere in the universe with a density close to the critical density  $\rho_c \approx 10^{-29} \text{ gm/cm}^3$ , then the mass in the void would be

approximately  $8.2 \times 10^{50}$  gm. This assumption follows closely the results of a recent measurement by Loh and Spillar of the mass density of the universe based upon the redshift and fluxes of 1000 field galaxies. They find that the density of matter is  $0.9 (+0.7, -0.5)$  the critical mass density at the 95% confidence level. Their method is supposedly sensitive to any matter, dark or luminous.<sup>21</sup> It is interesting to note for later comparison that if all this matter had coalesced into a single gigantic Schwarzschild black hole, it would have a radius  $1.2 \times 10^{23}$  cm (or about 40 kpc) with an "internal density" of about  $1.1 \times 10^{-19}$  gm/cm<sup>3</sup>.

The surface temperature of a black hole is given by<sup>4,22</sup>

$$T = (8\pi M)^{-1} = 1.225 \times 10^{19} \text{ gm-K/M} \quad (1)$$

where M is given in grams. (In what follows, this should be taken as only approximate since the mass should be corrected for rotation.<sup>18</sup> The temperature and mass could be iterated in what follows, but this would not change our qualitative conclusion.) For a surface temperature of 3 K, the mass would be  $M_{3K} = 4.1 \times 10^{18}$  gm with radius  $R_{3K} = 6.1 \times 10^{-10}$  cm with internal density  $4.2 \times 10^{51}$  gm/cm<sup>3</sup>. Note that this radius is larger than the radius of a nucleus. Thus if all the mass of the cluster were concentrated in such black holes, there would be  $2.0 \times 10^{32}$  of them in the black hole fluid!

The spin of matter should give rise to a repulsion (or bounce) during the "final" collapse of the universe towards a singularity.<sup>23</sup> The same would be true for any fluid with sufficient spin density. Thus if the 3 K black holes have sufficient spin, they would be stable against further coalescence. This repulsion then avoids the further growth problem even for stiff matter.<sup>24</sup> Suppose that the relaxation

process has continued until the black hole fluid has attained a density comparable with nuclear density,  $\rho_n \approx 7 \times 10^9 \text{ gm/cm}^3$ . The 3 K black holes would have a relative separation of the order of  $5.2 \times 10^2 \text{ cm}$  and a root mean square fluid velocity of  $1.7 \times 10^{-17} \text{ cm/s}$ . Such numbers give a new meaning to the concept of "stiff" matter used below. The close-packed "radius" of the fluid would be about  $30 \times 10^{13} \text{ cm}$ , and thus the fluid could be contained in a region within the orbit of Jupiter. This should be compared with the gigantic supercluster-sized black hole mentioned above. Although such a large black hole is possible, the surface temperature is far below the background 3 K black body radiation and thus should give rise to some detectable multipole components to the uniform blackbody radiation. Experimental data, however, seems to exclude this possibility<sup>19</sup> although there is now reasonable evidence that large black holes with mass of the order of  $10^{6-8}$  solar masses are contained in the nuclei of galaxies.<sup>25</sup> Such masses are consistent with previously observed mass distributions in spiral galaxies providing the mass of the black hole is less than 10% of the mass of the galaxy.<sup>26</sup> Within the context of our arguments here, the spin was not able to prevent coalescence.

We now investigate how spin can prevent the fluid from collapsing. It can be shown that for a fluid with randomly oriented spin density, the renormalized pressure and energy density is given by

$$p' = p - 2\pi G s^2/c^2 \quad (2)$$

and

$$\rho' = \rho - 2\pi G s^2/c^4 \quad (3)$$

where  $G$  is the gravitational constant,  $c$  is the speed of light, and  $s$  is the spin density. Let the renormalized density be of the order of nuclear density and let the fluid be ideal. Then

$$p - (2\pi G/c^2)s^2 = \rho_n kT/m_{3K} \quad (4)$$

For a stiff fluid,  $p = \rho_n c^2$ , then

$$\rho_n c^2 - (2\pi G/c^2)s^2 = \rho_n kT/m_{3K} \quad (5)$$

and

$$s^2 = (\rho_n c^4/2\pi G)[1 - kT/m_{3K}c^2] \quad (6)$$

For  $T = 3K$  and  $M_{3K} = 4.1 \times 10^{18}$  gm, we note that

$$kT/m_{3K}c^2 = 1.1 \times 10^{-55} \quad (7)$$

and the spin density

$$s = 1.2 \times 10^{29} \text{ gm/cm-s.} \quad (8)$$

This is the spin density that gives an energy density comparable with the nuclear energy density and thus prevents collapse of the fluid into a larger black hole.

We note the "fine tuning" of the energy associated with the fluid temperature to that of the rest mass energy of the fluid "particles" to one part in  $10^{55}$ . Such fine tuning between present epoch astronomical data compared with initial conditions in the big bang has been noticed consistently before.

Experimental evidence indicates that large compact objects are contained in the cores of some galaxies. Thus galaxies (and necessarily clusters) may have passed beyond fluid state so that they contain a large black hole core or even a small black hole fluid core. This is precisely what one would expect on the average for a system so finely tuned. Thus for galaxies the initial state was also a black hole fluid; however the "particle" mass of the fluid did not grow sufficiently to

avoid the Hawking evaporation up to the present epoch. For particle masses of the order of  $10^{14-15}$  gm, we now have a possible mechanism and source for the emission of energy by a quasar. Since the black hole fluid is much more concentrated than a single black hole of comparable mass, the size of the emission regions would no longer be a source problem for quasar emission. If this hypothesis is correct, then some quasars could be relatively close providing the particle masses were large enough. For example, quasars with  $z < 0.2$  are known but are rare compared with those with  $z > 1$ . It is interesting to speculate that the most spectacular event that we might observe would be the "turning on" of a quasar, or even a galactic nucleus, e.g. the brightening by a factor of two of 3C147 over a period of six years although this is normally attributed to relativistic motion within the core.<sup>27</sup> We also speculate that the spin axes of the black hole fluid would tend to align over the accretion period of the fluid since anti-alignment would favor particle coalescence. The total spin (not including any overall orbital angular momentum) of the black hole fluid would then be  $S = v_{3K} s = 1.4 \times 10^{70}$  gm cm<sup>2</sup>/s. Muradian has shown that astronomical objects seem to group into two angular momentum, J, classes:<sup>28</sup>  $J = \frac{1}{2} (M/m_p)^{4/3}$  for planets and stars, and  $J = \frac{1}{2} (M/m_p)^{3/2}$  for galaxies and clusters where  $m_p$  is the mass of a proton. For the 4/3 exponent,  $J \approx 1.1 \times 10^{72}$  gm cm<sup>2</sup>/s, whereas for the 3/2 exponent, J is twelve orders of magnitude larger. Thus the total spin of the black hole fluid compares well with the observed angular momentum relationship for planets and stars. We speculate that this implies that local black hole evaporation provides the seed perturbation for stars instead of galaxies whereas the overall orbital motion is imparted to the galaxy (or cluster) as a



whole. Also the fluid would represent in its mature stages a compact polarized medium (object) which could explain the directionality and perhaps the strength of jets (radio lobes) from quasars.

Finally the overall consequence is that the dark matter in the universe which is concentrated in the "voids" should be of the same order of magnitude as visible matter in the universe. On the basis of this scenario, the universe would probably be closed.

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